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Subedi et al.

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(54) **COMBLINE-CAVITY DUPLEXER, DUPLEXING APPARATUS, AND ANTENNA SYSTEM FOR FREQUENCY DIVISION DUPLEXING OPERATION**

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H01P 1/202 (2006.01)
H01P 7/04 (2006.01)
H01P 1/20 (2006.01)

(52) **U.S. Cl.**

CPC ***H01P 1/20*** (2013.01); ***H01P 1/2136*** (2013.01); *H01P 1/202* (2013.01); *H01P 7/04* (2013.01)

(58) **Field of Classification Search**

CPC H01P 1/208; H01P 1/2133; H01P 1/2136; H01P 7/04; H01P 1/2053; H01P 1/202
USPC 333/208, 123, 126, 129, 132, 206, 207,333/222–225, 202
See application file for complete search history.

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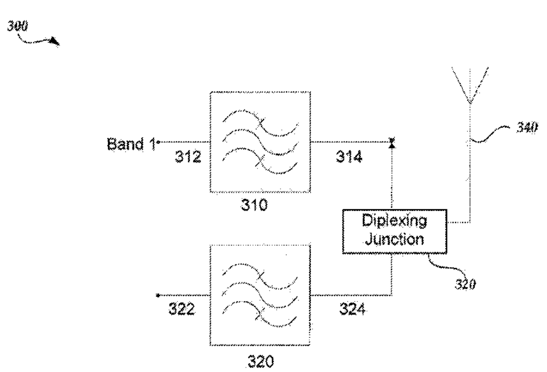
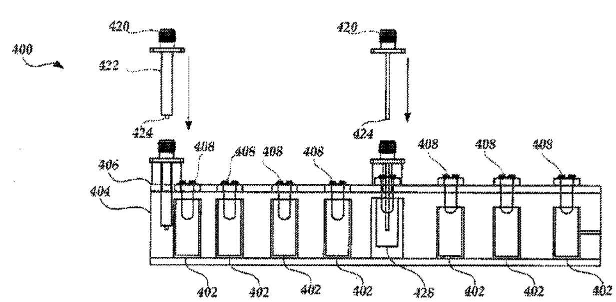
(57) **ABSTRACT**

The present disclosure relates to microwave cavity filters used in cellular communication systems. More specifically, in one aspect, the present disclosure relates to the integration of combline cavity filters directly with antenna elements without galvanic connections. In another aspect, the present disclosure relates methods for loading combline filters without contact.

24 Claims, 8 Drawing Sheets





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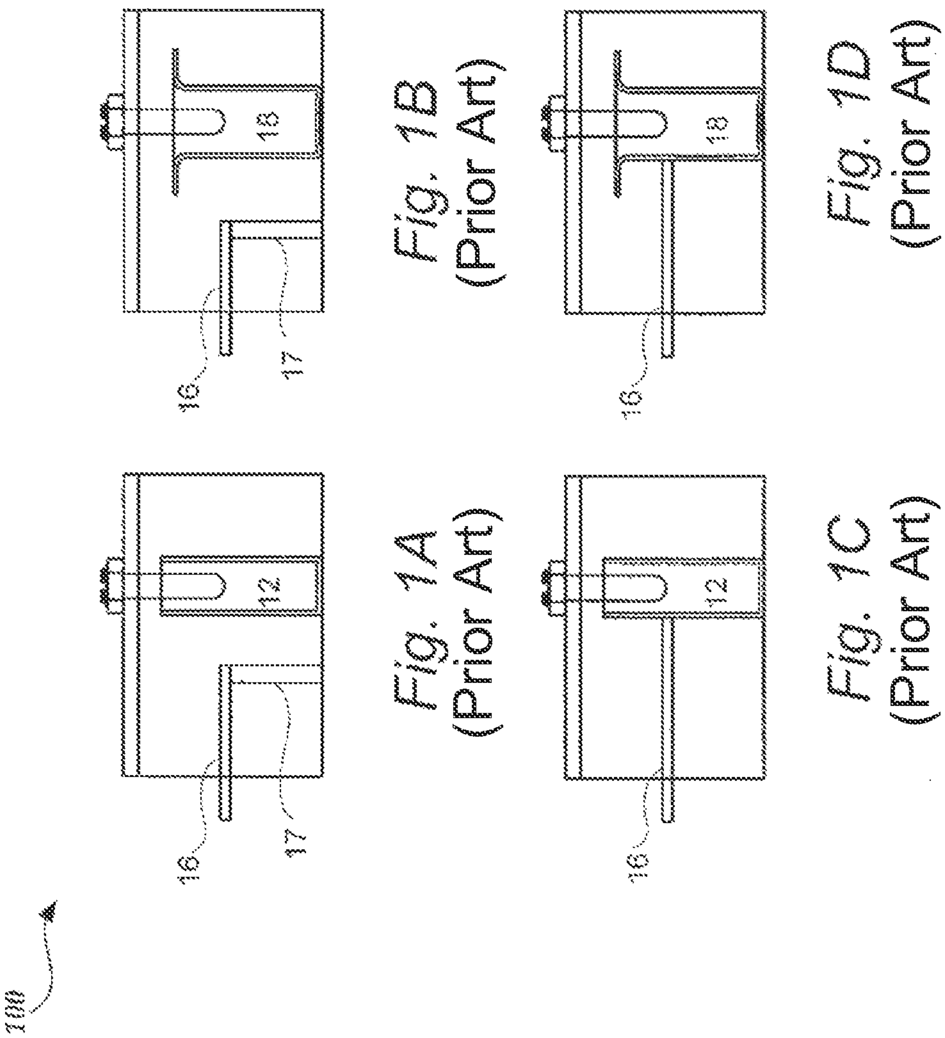


Fig. 1A (Prior Art)

Fig. 1B (Prior Art)

Fig. 1C (Prior Art)

Fig. 1D (Prior Art)

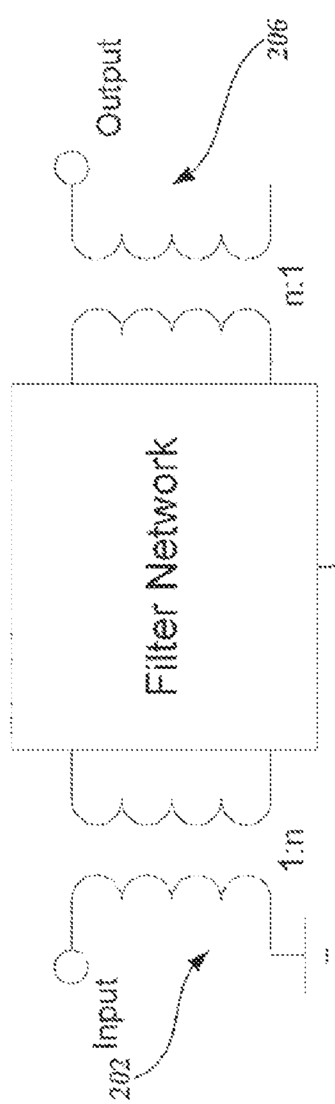

Input
202
1:n
Filter Network
204
n:1
Output
206

Fig.2A

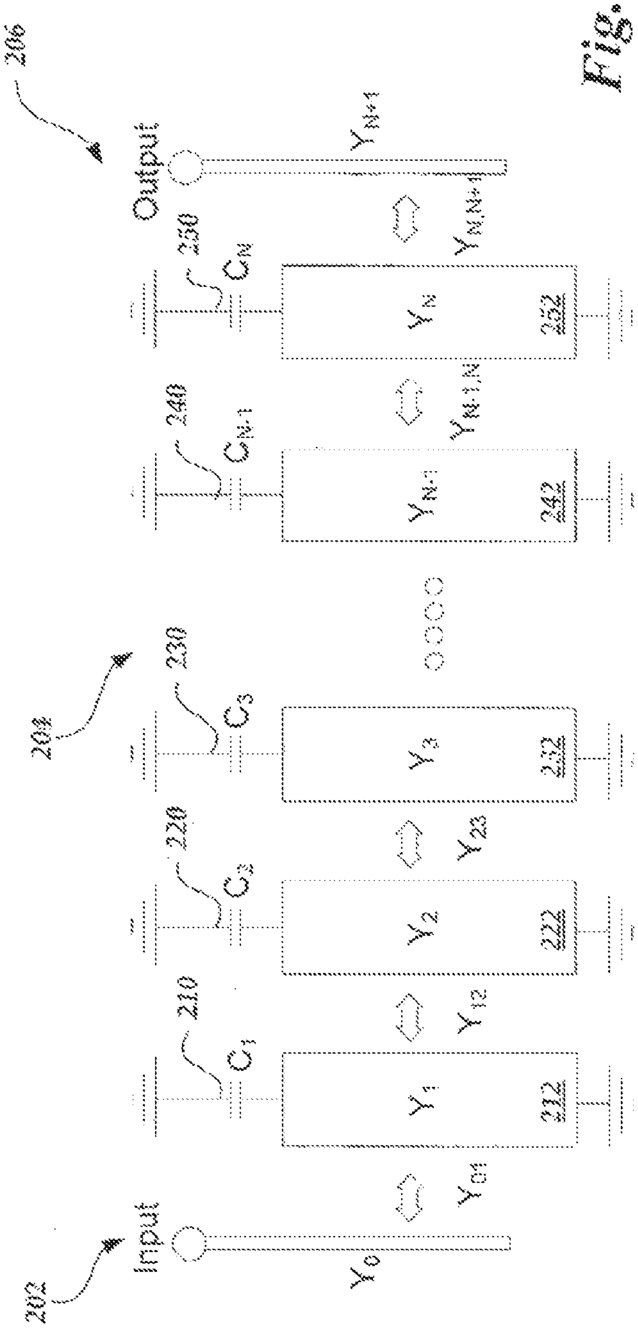
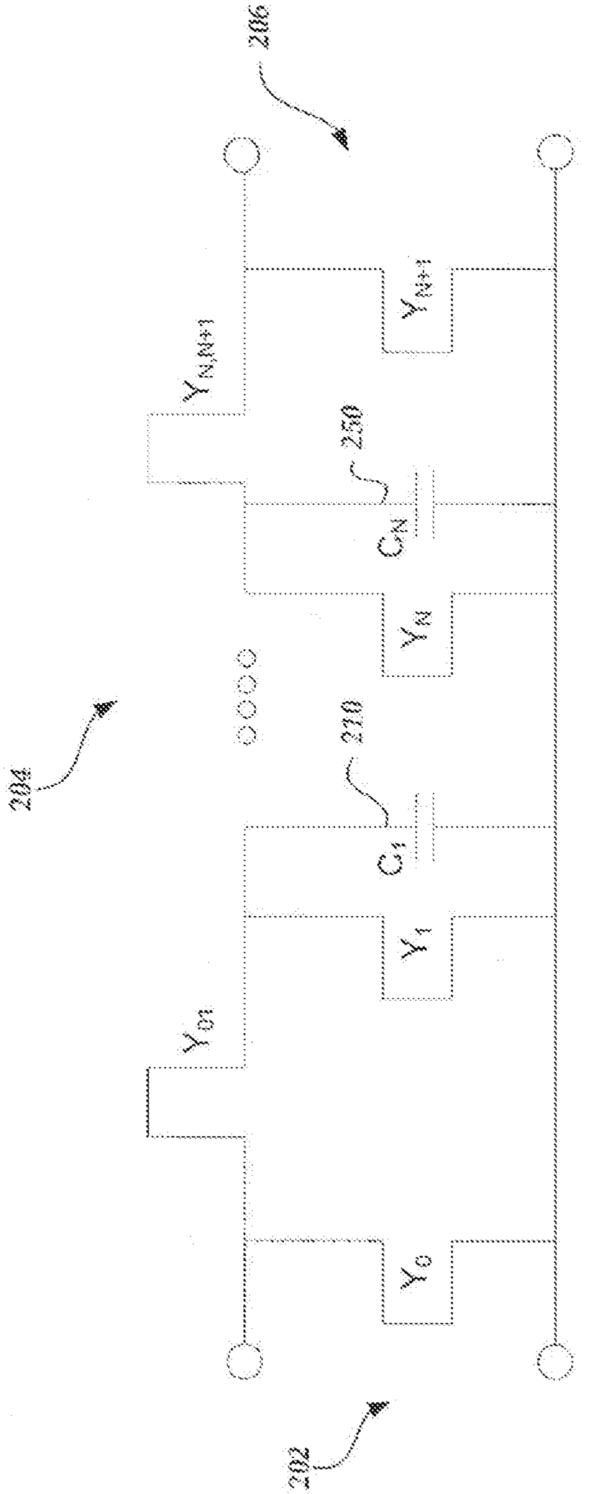

Input
202
Y_0
Y_{01}
Y_1
212
C_1
210
Y_{12}
Y_2
222
C_2
220
Y_{23}
Y_3
232
C_3
230
204
Y_{N-1}
242
C_{N-1}
240
$Y_{N-1,N}$
Y_N
252
C_N
250
$Y_{N,N+1}$
Y_{N+1}
Output
206

Fig.2B



Equivalent Circuit

Fig 2C

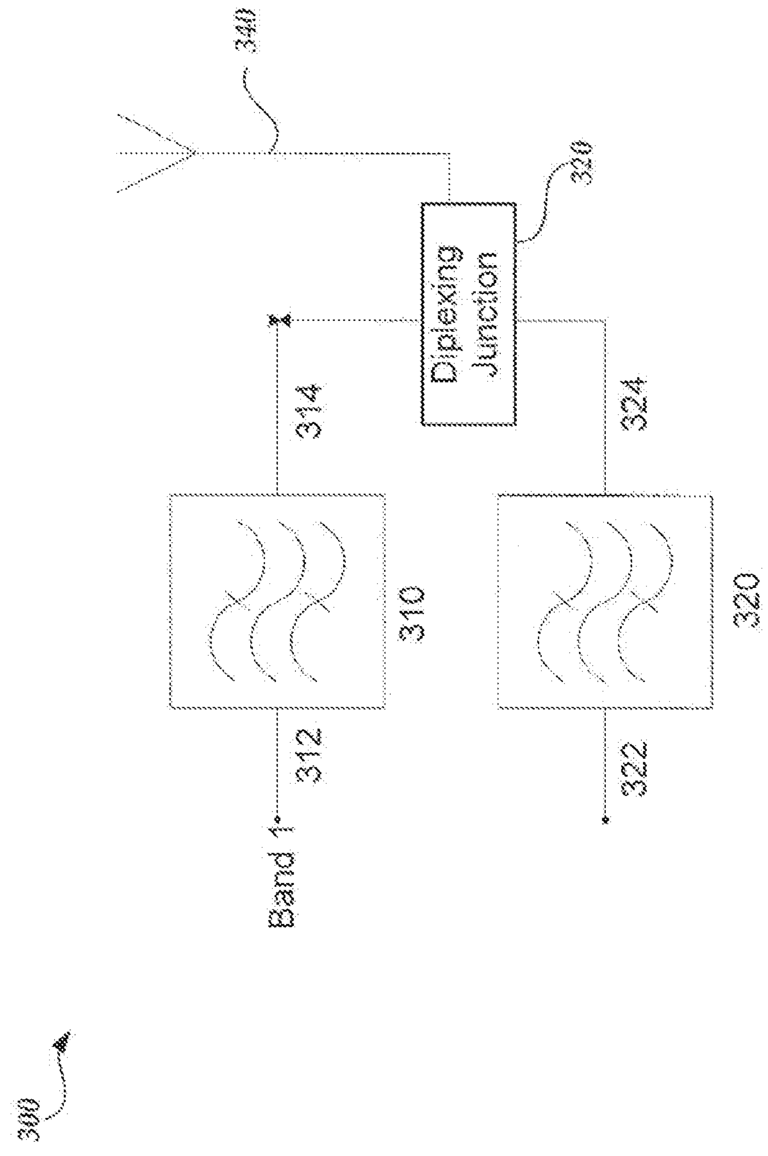


Fig.3

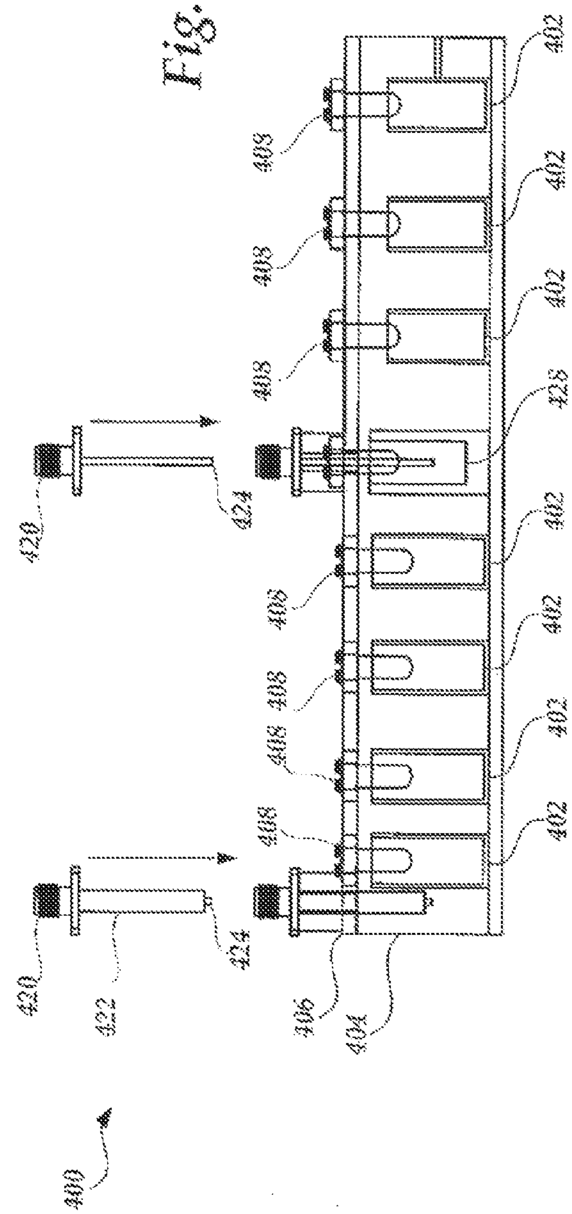


Fig. 4A

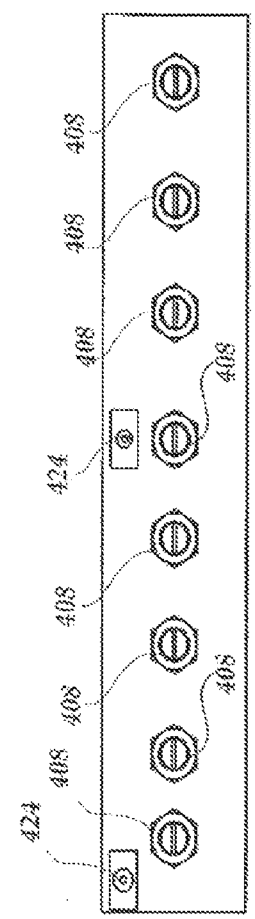


Fig. 4B

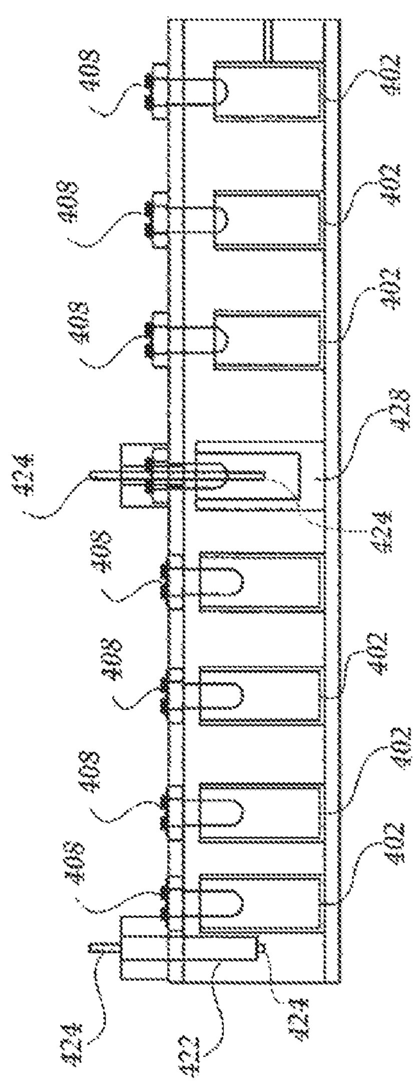

408
408
408
408
408
408
408
402
402
402
402
402
402
428
424
424
424
424
422

Fig.4C

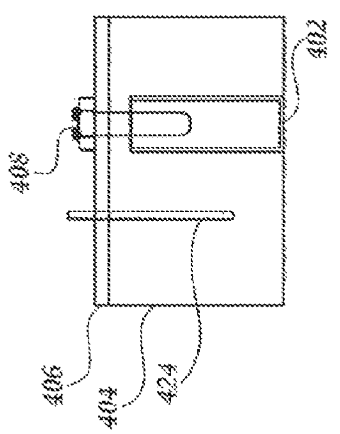


Fig. 5A

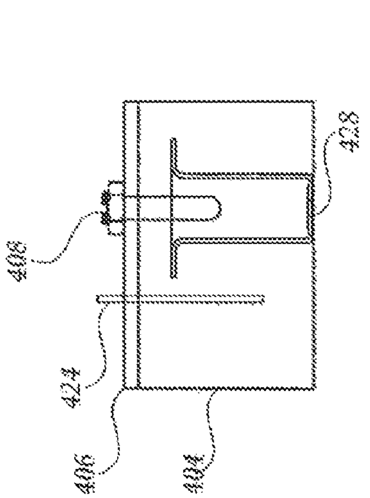


Fig. 5B

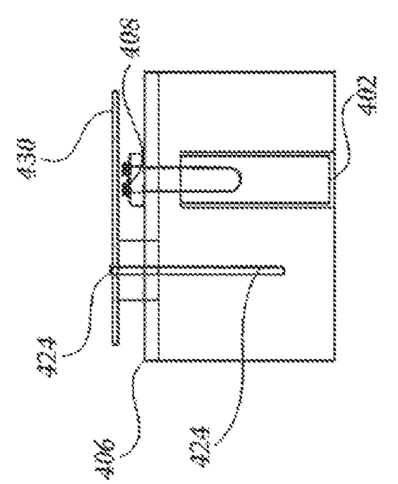


Fig. 5C

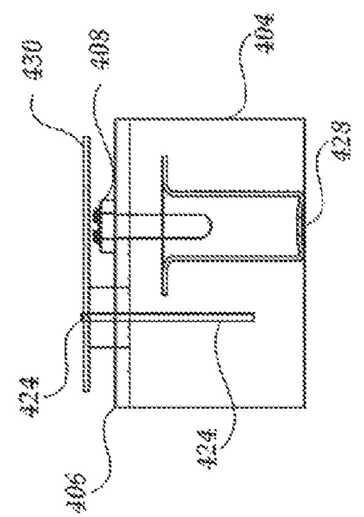


Fig. 5D

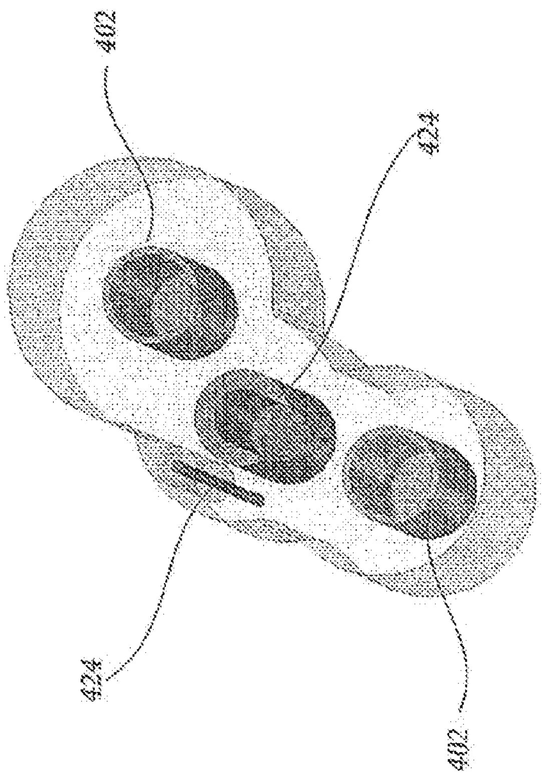


Fig.6

COMBLINE-CAVITY DUPLEXER, DUPLEXING APPARATUS, AND ANTENNA SYSTEM FOR FREQUENCY DIVISION DUPLEXING OPERATION

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Patent Application No. 61/531,306, entitled OPEN CIRCUIT COMMON JUNCTION FEED FOR DUPLEXER and filed on Sep. 6, 2011, the entirety of which is incorporated herein by reference.

BACKGROUND

Complete base station functionality may be housed inside a radome enclosure. Therefore, interconnecting different modules within the enclosure in the most efficient way for performance, size and ease of assembly becomes very critical. Recently, there has been increased integration of all of the transmitting and receiving components, such as the duplexers/filters, the antenna patches, the power amplifiers, the low noise amplifiers, the phase shifters, digital signal processing and other control electronics inside the radome enclosure itself. Such integrated antenna radio systems are known as active antenna arrays (AAA). One advantage of AAAs is that traditionally bulky radio systems can be shrunk to almost the size of the antenna itself, thereby eliminating external RF connectors and RF coaxial cables. Only data and power lines may be input to AAAs, resulting in significant performance enhancement with reduced power consumption.

In an integrated architecture, the improvements in the link budget are seen to be around 3 dB to 5 dB. Such link budget improvements imply that the traditional base station's coverage radius is increased by close to 100%, and the total power consumption is reduced by as much as 40%, thereby creating a higher performing system for lower cost. Since antenna systems are typically placed in elevated locations, weight is preferred to be as light as possible, with the goal being for one person lift. Therefore, any integration that can be done without requiring additional parts has not only mechanical advantages in terms of weight and ease of assembly, but also significant performance advantages. Traditional methods of coupling and feeding require an internal galvanic connection. Such a galvanic connection may be subject to difficulties in assembly, may introduce losses, and may also be prone to intermodulation in case of intermittent connections.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing aspects and many of the attendant advantages of this invention will become more readily appreciated as the same become better understood by reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

FIGS. **1**A-**1**D illustrate input/output coupling techniques used in the prior art.

FIGS. **2**A-**2**C illustrate basic combline filter theory.

FIG. **3** illustrates a duplexer including a duplexing junction and the antenna.

FIGS. **4**A-**4**C depict embodiments of the duplexing junction.

FIGS. **5**A-D depict embodiments of the duplexing junction.

FIG. **6** illustrates a top view of an embodiment of the duplexing junction.

DETAILED DESCRIPTION

The present disclosure relates to microwave cavity filters used in cellular communication systems. More specifically, in one aspect, the present disclosure relates to the integration of combline cavity filters directly with antenna elements without galvanic connections. In another aspect, the present disclosure relates methods for loading combline filters without contact. One skilled in the relevant art will appreciate, however, the additional or alternative aspects may be evident in accordance with the present disclosure.

Embodiments of this invention provide many advantages, including eliminating connectors and long transmission lines to connect to the antenna elements and thus making the whole antenna lighter in weight and reducing path loss. By way of an illustrative example, in a traditional six element array, there would be 24 connectors (12 on the duplexer side and 12 on the antenna side) and 12 transmission cables required to make connections between antenna patches and the diplexers. As previously described, each of these connections would increase the cost and complexity of manufacture and could be the source, at least in part, to losses experienced by the operating of the array. In accordance with the present disclosure, a six element array implementing the disclosed coupling technique would mitigate the losses associated with the traditional connections. Additionally, the six element array would likely be easier to assemble and would experience an additional potential reduction of passive intermodulation production from the duplexing junction since there is no galvanic connection in embodiments of this invention.

Embodiments of the invention will be described in reference with the accompanying figures. It shall be understood that the following description, together with numerous specific details, may not contain certain details that may have been omitted as it shall be understood that numerous variations are possible and thus will be detracting from the full understanding of the present invention. It will be apparent, however, to those skilled in the art, that the present invention may be put into practice while utilizing various techniques.

FIGS. **1**A-**1**D illustrate input/output coupling techniques used in traditional junction. components. As illustrated in FIGS. **1**A-**1**D, input and output coupling is done by either directly connecting the center transmission line **16** into the resonator **12** (FIG. **1**A) (or a common resonator **18**, FIG. **1**B), or by connecting to a loading post **17** which is parallel to the resonator **12** (FIG. **1**C) (or to the common resonator **18**, FIG. **1**D) and is grounded at the opposite end.

For ease of understanding, basics of the theory of resonator operation are briefly described below in reference with FIGS. **2**A-**2**C. FIG. **2**A illustrates an input **202** to a filter network **204**, which in turn is connected to an output **206**. As illustrated in FIG. **2**B, the filter network **204** can include combline filters **212**, **222**, **232**, **242** and **252** which are inductively coupled resonators with an electrical length less than about 90° degree, which are grounded at one end with capacitive tuning screws giving capacitances C**1** (**210**), C**2** (**220**), C**3** (**230**), C**4** (**240**) . . . CN (**250**) (for resonators **1**, **2** . . . N respectively), for fine adjustment at the other end. The desired performance helps to determine the number of these resonators used in a particular fitter. These resonators may be cross coupled either inductively or coactively for an asymmetric filter response. For example, it is possible to have more selective resonators on one side of the pass band than the other side of the pass band. Such an asymmetric response may be more typical in real world applications. An equivalent circuit of the filter network **204** is illustrated in FIG. **2**C.

One skilled in the relevant art will appreciate that voltages V_N at the end of each resonator are related to the currents I_N in accordance with the following matrix, sometimes referred to as the admittance matrix:

$$\begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ \vdots \\ I_{N-1} \\ I_N \end{bmatrix} = \frac{1}{\tanh\left(\frac{l}{v}\right)} \begin{bmatrix} Y_{11} & -Y_{12} & 0 & 0 & \ldots & & \\ -Y_{12} & Y_{22} & -Y_{23} & 0 & & & \\ 0 & -Y_{23} & Y_{33} & -Y_{34} & & & \\ \vdots & & -Y_{34} & \ddots & & & \\ & & & & Y_{N-1,N-1} & -Y_{N-1,N} & \\ & & & & -Y_{N-1,N} & Y_{NN} & \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ \vdots \\ V_{N-1} \\ V_N \end{bmatrix} \quad (1)$$

where

Y_{ij} = the admittance matrix and with $i = 1$ to N and $j = 1$ to N.

l = length of resonators.

v = progagation velocity.

With one common port, two filters separated in bands of frequencies are called a duplexer or a diplexer; three filters separated by bands of frequencies are called a triplexer, four filters separated by bands of frequencies are called a quadplexer, and so on. More generally, a plurality of filters sharing a common port is called a multiplexer. An example of a duplexer **300** is shown FIG. **3**. Each filter, **310** and **320**, has an input port **312** and **322**, and an output port **314** and **324** respectively. The duplexer **300** includes a duplexing junction **320**, which is coupled to an antenna component **340** or antenna feed.

Illustratively, the display junction **320** can implement traditional methods of coupling illustrated in FIG. **1** require an internal galvanic connection. Such a galvanic connection may be subject to difficulties in assembly, and may also be prone to intermodulation in case of intermittent connections. Alternatively, the display junction component of the present disclosure may be implemented.

FIGS. **4**A-**4**C and **5**A-**5**D illustrative various embodiments for implementing the display junction **320** (FIG. **3**). As illustrated in FIGS. **4**A and **4**B, a main filter housing **404**, which may be made of metal, and may also include a main lid **406**, also made of metal, may house a plurality of resonators **402**. The housing **404** may also include a common resonator **428**, common to both transmit and receive filters. The resonators **402** and the common resonator **428** may be locked down inside the main housing **13** through a tuning screw and nut assembly **408**. The assembly **408** may be moved up and down to be locked down.

The amount of required coupling of RF energy into the filter is dependent on the proximity to the resonator **402**, **428** and also to the penetration of a probe **426** into the housing **404**. In some embodiments, a probe **424** may be used to perform the coupling. Generally, the longer the probe **424** is, the stronger the coupling is. The depth of the probe **424** penetration may be practically limited by the dimensions of the housing **404**. The probe **424** may be designed to be about a few millimeters away from the floor of the housing **404**. In various embodiments, this probe **424** may be either bare metal or it can be covered with a dielectric material as known in the art. Traditionally, the inputs and outputs of the filter would be connected to the resonator **402** or **428** through direct soldering, screwing or pressing. Embodiments disclosed herein enable tuning of the filter without a direct metal to metal contact, but rather through coupling with a probe **424** without a galvanic contact.

With continued reference to FIG. **4**A, the filter **400** may be tuned with connectors **420** having center pins **426** connected to the connectors **420**. In some embodiments, the connector **426** may be an open circuited bare wire, such as the connector shown in the middle top of FIG. **4**A. In other embodiments, the bare wire may be covered with insulation **422**, which may be made of suitable insulating materials. The insulation **422** ensures that the common junction does not touch the resonators **402**. Additionally, the insulation **422** may help increase coupling compared to just air dielectric which can also be used for additional tuning flexibility.

When the filter is tuned satisfactorily, the connector **420** with the center pin **424** can be removed and a new center pin with the same dimensions (including diameter) can be inserted, which will provide greater flexibility to connect other modules to the filter. As illustrated in FIG. **4**C, in other embodiments, only the connector **420** may be removed, keeping the center pin **424** in place. In some applications, the center pin **424** can be just the center pin of the connector, i.e. a connector having a long center pin **424** may be used as the open circuited probe. In other embodiments, the center pin **424** may be covered with insulation **422**.

FIG. **5**A-**5**D illustrate embodiments where the probes protrude from the cover **406** of the housing **404**. FIGS. **5**A-**5**D show only the first Ix and the first Rx resonator **402**, or only the common resonator **428** of the filter for ease of illustration. A metal probe **424** coming down parallel to the resonators **402** (FIGS. **5**A and **5**C) or the common resonator **428** (FIGS. **5**B and **5**D) is capable of coupling the RF energy in to the filter. In some embodiments, such as those shown in FIGS. **5**C and **5**D, a circuit board **430** may be placed with the probe **424** sticking through it, and the probe may be soldered to the trace on the circuit board **430**. As illustrated in FIGS. **5**A-**5**D, the probe **424** eliminates the need for a galvanic connection at the antenna junction. As previously discussed, the use of the probe connection to the resonator allows the antenna feed element to be directly connected without additional cables and connectors.

FIG. **6** illustrates a top view of an embodiment of the duplexing junction. FIG. **6** illustrates a common resonator **428** coupled using an open ended probe **424**. For ease of understanding, only the first Tx and the first Rx resonator **402** of the antenna are shown, but several resonators may be present in the housing.

Embodiments disclosed herein enable direct integration of the duplexer common junction with an open ended probe loading with the antenna feed in an antenna array system. Combline cavity duplexers used in a picocell, a femto cell and active antenna array communication systems may use the open circuited coupling disclosed. Microwave combline filters can also use the disclosed open circuited probe couplings. Also disclosed are methods of interfacing microwave combline filters having open circuited probe couplings with any external device. A long center connector pin may be used as the open circuited coupling probe.

While illustrative embodiments have been disclosed and discussed, one skilled in the relevant art will appreciate that additional or alternative embodiments may be implemented within the spirit and scope of the present disclosure. Additionally, although many embodiments have been indicated as illustrative, one skilled in the relevant art will appreciate that the illustrative embodiments do not need to be combined or implemented together. As such, some illustrative embodiments do not need to be utilized or implemented in accordance with the scope of variations to the present disclosure.

Conditional language, such as, among others, "can," "could," "might," or "may," unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements or steps. Thus, such conditional language is not generally intended to imply that features, elements or steps are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without user input or prompting, whether these features, elements or steps are included or are to be performed in any particular embodiment. Moreover, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey utilization of the conjunction "or" in enumerating a list of elements does not limit the selection of only a single element and can include the combination of two or more elements.

Any process descriptions, elements, or blocks in the flow diagrams described herein and/or depicted in the attached figures should be understood as potentially representing modules, segments, or portions of code which include one or more executable instructions for implementing specific logical functions or steps in the process. Alternate implementations are included within the scope of the embodiments described herein in which elements or functions may be deleted, executed out of order from that shown or discussed, including substantially concurrently or in reverse order, depending on the functionality involved, as would be understood by those skilled in the art. It will further be appreciated that the data and/or components described above may be stored on a computer-readable medium and loaded into memory of the computing device using a drive mechanism associated with a computer-readable medium storing the computer executable components, such as a CD-ROM, DVD-ROM, or network interface. Further, the component and/or data can be included in a single device or distributed in any manner. Accordingly, general purpose computing devices may be configured to implement the processes, algorithms and methodology of the present disclosure with the processing and/or execution of the various data and/or components described above. Alternatively, some or all of the methods described herein may alternatively be embodied in specialized computer hardware. In addition, the components referred to herein may be implemented in hardware, software, firmware or a combination thereof.

It should be emphasized that many variations and modifications may be made to the above-described embodiments, the elements of which are to be understood as being among other acceptable examples. All such modifications and variations are intended to be included herein within the scope of this disclosure and protected by the following claims.

What is claimed is:

1. A combline-cavity duplexer comprising:

a housing encompassing:

a plurality of individual resonators including a set of transmit (TX) resonators and a set of receiver (RX) resonators, each of the plurality of individual resonators having a defined capacitance and individually grounded;

one or more common resonators, the one or more common resonators being common to the set of transmit resonators and the set of receive resonators;

wherein the plurality of individual resonators and the one or more common resonators are all provided within a single common cavity of the housing to forma combline cavity filter configured to operate as a filter network,

wherein the filter network comprises a transmit filter and a receive filter to provide separate frequency bands for concurrent transmission and reception for frequency division duplexing operation,

wherein the transmit filter comprises the set of transmit resonators and the one or more common resonators,

wherein the receive filter comprises the set of receive resonators and the one or more common resonators; and

a set of open-circuited probes, the probes to couple signals within the common cavity from the plurality of individual resonators and the one or more common resonators to one or more external components through open-circuit probe coupling independent of a galvanic contact with the plurality of individual resonators or the one or more common resonators.

2. The combline-cavity duplexer as recited in claim **1** further comprising a screw and nut assembly for tuning the plurality of individual resonators and the one or more common resonators by controlling a depth associated with the screw.

3. The combline-cavity duplexer as recited in claim **1** further comprising a lid.

4. The combline-cavity duplexer as recited in claim **3**, wherein at least one probe of the set of probes includes a connector mounted on the lid.

5. The combline-cavity duplexer as recited in claim **3**, wherein at least one of the probes extrudes through the lid,

wherein the at least one probe is are open ended and comprises a center conductor in parallel with the individual resonators, the center conductor extending into the common cavity without having galvanic contact with the lid or the housing, and

wherein the individual resonators are cylindrically shaped having an open end exposed to the common cavity without contacting the housing.

6. The combline-cavity duplexer as recited in claim **5** further comprising a circuit board mounted above the lid, wherein the circuit board includes an opening for the at least one probe extruding through the lid.

7. The combline-cavity duplexer as recited in claim **1**, wherein at least one probe in the set of probes includes an insulation layer.

8. The combline-cavity duplexer as recited in claim **1**, wherein at least one probe in the set of probes corresponds to a center pin associated with the at least one common resonator.

9. The combline-cavity duplexer as recited in claim **8**, wherein each center pin corresponds to a bare wire.

10. The combline-cavity duplexer as recited in claim **1**,

wherein a first probe of the set of probes is configured to be coupled with an external antenna, a second probe of the set of probes is configured to be coupled to a receive signal path, and a third probe of the set of probes is configured to be coupled to a transmit signal path, and

wherein the receive filter is configured to filter signals for the receive signal path and the transmit filter is configured to filter signals for the transmit signal path.

11. The combline-cavity duplexer as recited in claim **1**, wherein the combline-cavity duplexer is part of an antenna system.

12. The combline-cavity duplexer as recited in claim **11**, wherein the antenna system is configured to be part of a cellular base station or enhanced node B (eNB) of a cellular network.

13. A duplexing apparatus comprising:

a plurality of resonators all provided within a single common cavity of a housing to form a combline cavity filter configured to operate as a filter network, each resonator being individually grounded; and

a set of open-circuited probes, the probes configured to couple signals within the common cavity from the plurality of resonators to one or more external components through open-circuit probe coupling independent of a galvanic contact with the plurality of resonators,

wherein the plurality of resonators are configured to provide a transmit filter and a receive filter in separate frequency bands for concurrent transmission and reception for frequency division duplexing operation, the plurality of resonators including one or more common resonators.

14. The duplexing apparatus as recited in claim **13**, wherein at least one of the probes is configured to include a connector mounted on a lid associated with the duplexing apparatus.

15. The duplexing apparatus as recited in claim **14**, wherein said at least one of the probes is configured to extrude through the lid associated with the duplexing apparatus.

16. The duplexing apparatus as recited in claim **13**, wherein at least one of the probes has an insulation layer.

17. The duplexing apparatus as recited in claim **13**, wherein at least one of the probes is configured to be coupled to an antenna feed.

18. The duplexing apparatus as recited in claim **13**, wherein the plurality of resonators are configured as a duplexer.

19. An antenna system comprising:

an antenna feed element; and

duplexer comprising:

a plurality of resonators including a set of transmit (TX) resonators and a set of receiver (RX) resonators, each of the plurality of resonators having a defined capacitance and individually grounded;

one or more common resonators, the one or more common resonators being common to the set of transmit resonators and the set of receive resonators;

wherein the plurality of resonators and the one or more common resonators are all provided within a single common cavity of the housing to form a combline cavity filter configured to operate as a filter network,

wherein the filter network comprises a transmit filter and a receive filter to provide separate frequency bands for concurrent transmission and reception for frequency division duplexing operation,

wherein the transmit fitter comprises the set of transmit resonators and the one or more common resonators, and

wherein the receive filter comprises the set of receive resonators and the one or more common resonators; and

a set of open-circuited probes, the probes to couple signals within the common cavity from the plurality of resonators to one or more external components including the antenna feed element through open-circuit probe coupling independent of a galvanic contact with the plurality of resonators.

20. The antenna system as recited in claim **19**,

wherein a first probe of the set of probes is configured to be coupled with the antenna feed element, a second probe of the set of probes is configured to be coupled to a receive signal path, and third probe of the set of probes is configured to be coupled to a transmit signal path, and

wherein the receive filter is configured to filter signals for the receive signal path and the transmit filter is configured to filter signals for the transmit signal path.

21. The antenna system as recited in claim **20**, wherein the antenna system is configured to be part of a cellular base station or enhanced node B (eNB) of a cellular network.

22. The antenna system as recited in claim **19**, wherein the set of probes includes a connector mounted on a lid associated with the apparatus.

23. The antenna system as recited in claim **22**, wherein the set of probes includes a probe extruding through the lid associated with the apparatus.

24. The antenna system as recited in claim **19**, wherein the set of probes includes at least one probe having an insulation layer.

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